RILEM Technical Letters (2023) 8: 176-181
https://doi.org/10.21809/rilemtechlett.2023.189

Summary of RILEM Technical Committee TC 279-WMR activities

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Received: 09 October 2023 / Accepted: 14 May 2024 / Published online: 05 Sep 2024

Abstract

Several alternative paving materials, namely plastic, crumb rubber, steel slag, and construction and demolition waste, were incorporated into the construction of road pavements, highlighting their favorable environmental and economic outcomes. Despite the considerable demand for such sustainable practices, the effort is mainly confined to research activities and within a limited number of countries, preventing further advancements and broader validation capable of reaching full acceptance at the market level for alternative road materials. RILEM TC 279-WMR "Valorisation of Waste and Secondary Materials for Roads" sought to promote the adoption of these alternative paving materials based on inter-laboratory activities addressing the behavior of the bituminous blends designed with marginal materials aiming to define tailored methodologies targeting selection, preparation, and use at the production level. Experimental results indicate that using alternative materials can result in similar performance compared to the corresponding virgin materials, keeping in mind that mix designs might need to be adjusted, for example, using higher binder content. In addition, adopting appropriate test procedures is essential as such new composite can be susceptible to specific failure modes or scale effects. Furthermore, despite the mechanical performance, environmental and life cycle assessments need to be evaluated to ensure that such materials are sustainable and valuable.

Keywords: Asphalt; Bitumen; Waste; Performance; LCA

1 Introduction

The amount of waste worldwide is alarmingly growing, as seen in the example from Europe [1]. In spite of major advances in waste material recycling, numerous regulations and criteria restrict these resources from re-iterating their use in the same value chain. Therefore, other uses for these materials must be defined and implemented to avoid landfilling. Many secondary materials, such as recycled concrete aggregates, steel slag, waste plastic, or crumb rubber produced from end-of-life tires (ELTs), can find application in roads, showing similar or even better performance [2]. Although their use has been proven at the research level, the broader application is missing. This is primarily due to a lack of standards and incentives for their use.

The RILEM Technical Committee TC 279-WMR "Valorisation of Waste and Secondary Materials for Roads aimed to advance the knowledge on the application of marginal materials for roads by performing inter-laboratory activities to evaluate the performance of bituminous blends containing such alternative materials and ultimately leading to the tailored standardized methods for selection, adoption, and incorporation. Consequently, the sustainability of selected mixtures was compared to corresponding virgin mixtures, relying on a life cycle assessment (LCA) process.

In order to achieve these goals, four Technical Groups (TG) were designed to address all aspects of this topic:

TG1: Waste plastic modified asphalt binders

TG2: Crumb rubber modified asphalt binders

TG3: Waste aggregates in asphalt mixtures

TG4: Life cycle assessment

All TGs were active during the lifetime of the TC. Below is a brief summary of the TG activities. More detailed information can be found in the State of the art (STAR) report [3] as well as dedicated publications [3-8].

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TG1: Waste plastic modified asphalt binders and mixtures

The behavior and impact of incorporating waste Polyethylene (PE) asphalt binders was addressed by Task Group 1 (TG1). Then, the possible inclusion of waste PE into asphalt mixtures was also evaluated in cooperation with Task Group 3 (TG3). The waste PE used in this project was obtained from a recycling plant in Switzerland.

The binder research activity was conducted based on a protocol accepted by eleven participating institutions and developed as part of the TG work in order to reduce experimental differences and their effect on the results. The amount of PE blends was 5 % of plastic waste and 95 % bitumen. The protocol included temperature (170°C), and high shear mixing and time (3500 rpm for 1h). The results obtained from binder testing with the Multiple Stress Creep and Recovery (MSCR) procedure indicate a superior response of the PE-modified binder against permanent deformation. In terms of fatigue performance, the Linear Amplitude Sweep (LAS) experimentation suggests a better response at lower strain for PE blends with a reduced fatigue life when the strain level was increased, most likely associated with an increase in brittleness. Figure 1 presents an example of the round robin experimental results showing the measurements of the complex modulus for the binder blends, indicating that the reproducibility decreases as the temperature increases. This is a result of the inhomogeneity of the binder blends. As a waste material is used, there are inherent inhomogeneities in the material that become prevalent as the binder becomes softer with temperature.

As far as the use of waste PE into asphalt mixtures concerns, 11 labs already participating to TG1 and/or TG3 experimentations were involved. Participants could select aggregates and asphalt binders locally, while the same PE plastic was delivered to each laboratory. PE was added by the dry process to avoid potential limitations associated with stability and inhomogeneity, as experienced during the testing campaign on the binder. The reproducibility was better for the mixture experiments at lower dosages of PE and worst at higher dosages, as shown in the example of ITS (Figure 2). The PE-modified mixtures showed improved workability and increased strength. More consistent increase in indirect tensile strength (ITS) were achieved for higher content of plastic when compared to the mixture without PE, most likely associated with enhanced plastic-modified mastic cohesion. The stiffness measurement indicated that the incorporation of plastic moved the response of the material toward a more elastic-like domain reducing the viscous component. Also, with respect to the cyclic compression tests, the addition of plastic beneficially impacted the material performance resulting in lower creep rate and higher values of creep modulus. This trend is supported by the results obtained from the wheel tracking method. Incorporating plastic provided also a positive contribution in terms of moisture resistance with similar of better response than reference material.

The work conducted in TG1 on PE binders and TG1+TG3 on mixtures can be summarized in the following essential conclusions:

- The PE-modified binders present better performance against permanent deformation compared unmodified materials.
- The fatigue response of binder containing plastic is superior compared to unmodified ones for small strain levels; on the other hand, they exhibit shorter fatigue life as the imposed strain increases.
- The workability of the asphalt mixture is not substantially affected by the incorporation of plastic.
- Higher Indirect Tensile Strength (ITS) values are obtained as the content of plastic increases. Such results may be associated with an enhanced plastic-modified mastic system cohesion.
- The PE-modified mixtures present a shift toward a more elastic behavior in terms of stiffness. This result is associated with a lower creep rate and enhanced creep modulus, further supported by the wheel tracking tests output.
- In terms of resistance to moisture damage, the mixture containing plastic exhibited better performance with respect to the reference nonmodified mixtures.

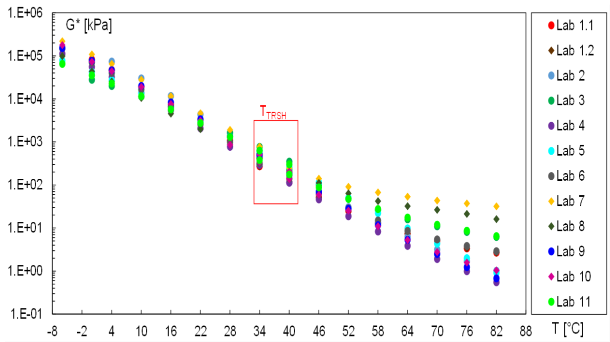

Figure 1. Complex modulus vs. temperature for PE-modified binders [4].

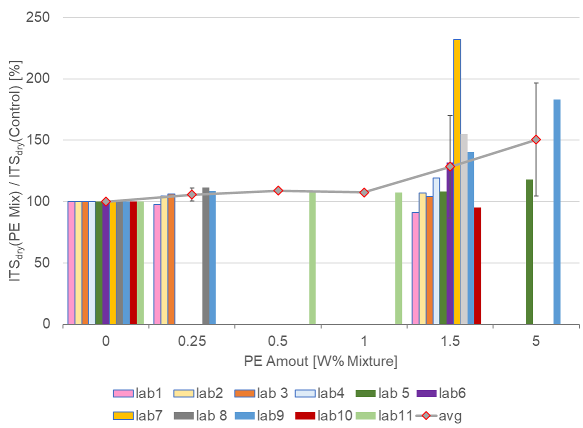

Figure 2. Indirect tensile strength, ITS increase as a function of waste PE content in asphalt mixtures [7].

TG2: Crumb rubber modified asphalt binders

The experimental work of task group 2 was on crumb rubber (CR) as a performance-enhancing additive for bitumen. Four laboratories participated in this TG. Our industrial partners provided four types of CR obtained from end-of-life tires (ELTs). The success of these binder blends was partially related to the crumb rubber modified bitumen (CRMB) viscosity. This property allows the use of more bitumen compared to conventional mixtures. CR surface contributes to the viscosity of the CRMB, and therefore, it is important to verify how different types of CR perform as a bitumen modifier. These four types of CR were produced using mechanical grinding, cryogenic process, waterjet pulverization, and reacted and activated rubber (RAR) were used for Inter-laboratory experiments. RAR is a special kind of crumb rubber that is modified with bitumen and filler. These industrial processes affect the surface texture and size of the resulting CR. Three types of penetration-graded base bitumen with 35/50, 50/70, and 70/100 were used for the modification. Thereafter, the CRMBs were investigated mechanically and chemically. Figure 3 shows a sample of the results of complex shear modulus as a function of CR type.

From the experimental results, the following can be concluded:

- The Fourier transform infrared (FTIR) spectroscopy analysis showed that there is only physical interaction between bitumen and CR.
- The round robin complex modulus master curves from different laboratories were similar. In the region with high-temperature or low-frequency adding CR to the bitumen resulted in a stiffening effect, whereas, on in the low-temperature/high-frequency domain, the stiffness was decrease.
- Although differences in empirical tests, namely penetration, softening point, and viscosity were observed, the complex shear modulus shows the bitumen's penetration value was the primary contributor to the CRMB response.

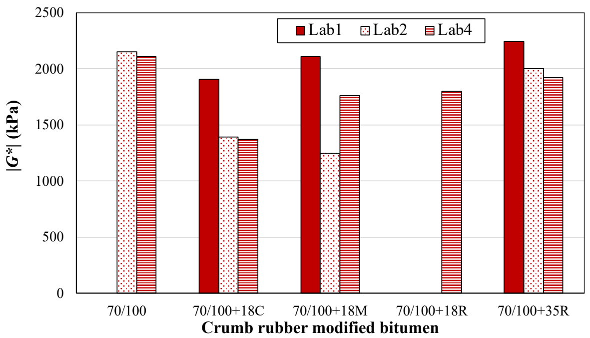

Figure 3. Complex modulus of control and modified binders; results from three laboratories [3].

TG3: Waste aggregates in asphalt mixtures

TG 3 incorporated several alternative aggregates as a replacement for natural aggregates in asphalt mixtures. To this end, construction and demolition waste, recycled concrete aggregates, and steel slag [8] were used. As an initial step, the following properties of aggregates were determined: particle density (PD), water absorption (WA), Los Angeles (LA), micro-Deval (MDE), sand equivalent (SE), methylene blue (MB), flakiness index (FI) and shape index (SI). It was observed that several waste aggregates would not meet the current criteria such as high water absorption, low Los Angeles and sand equivalent values and this would be a barrier for their eventual acceptance.

As part of the inter-laboratory program various amounts of local waste aggregates were substituted for virgin aggregates. Eight laboratories reported the results of mixtures with alternative aggregate and comparison to conventional ones using the gradation shown in Figure 4. The results show that mixtures produced with the alternative aggregates could fulfill the volumetric requirements but required higher amounts of bitumen. Overall independent of the type of aggregates, better mechanical performance was observed. The experimental results indicate that using alternative aggregates could be a viable option for pavements, making a contribution towards a zero-waste society and reducing the use of natural aggregates. Furthermore, in regions where good quality aggregates are scarce and long haul shipping is necessary to acquire good virgin aggregate, the use of aggregate substitutes becomes even more urgent for the reduction of greenhouse gases and energy use. However, appropriate quality control as well as acceptance guidelines, pavement design methods is needed., Furthermore, research to assess the environmental effect and life cycle sustainability of alternative materials, is recommended.

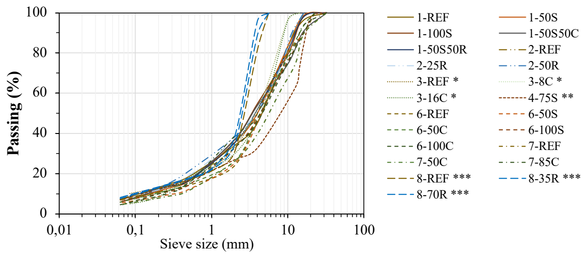

Figure 4. Aggregate gradation of all participating laboratories [3]

The following conclusions can be drawn from this study:

- In comparison to that of conventional aggregate, 30% higher particle density (PD) was measured for the steel slag aggregates (SS) in this study, showing a better resistance to fragmentation.
- Construction and demolition waste (CDW) materials used in this study had the worst aggregate characteristics in comparison to the other materials used. Specifically, lower Particle density (PD), lower sand equivalent (SE) values, higher water absorption (WA), higher Los Angeles abrasion loss (LA) when compared to other alternative and conventional materials. With respect to current technical specifications for asphalt mixtures, two limiting factors for use of CDW are high values of water absorption and low abrasion resistance
- RCA materials had, for the most part, worst properties in comparison to the conventional aggregates of limestone and sandstone and SS but better properties in comparison to CDW
- Marshall Stability and volumetric properties of the investigated mixtures were acceptable. However, in most cases more binder was needed. A direct relationship between the type of aggregate used

and the higher required bitumen content could be established. Furthermore steel slag had lower absorption as opposed to RCA and CDW which had high absorption values.

- The use of waste aggregates resulted in higher Marshall Stability (MS) values.
- The indirect tensile strength (ITS) values were not significantly affected through the use of alternative aggregates.
- With the exception of one, all mixtures fulfilled the water sensitivity criteria (Figure 5);
- The mixtures containing waste aggregates had lower permanent deformation in spite the fact that they had more binder content.
- With the exception of the results from one laboratory that tested SS mixtures, the waste aggregates had a positive effect on the indirect tensile stiffness modulus (ITSM) .

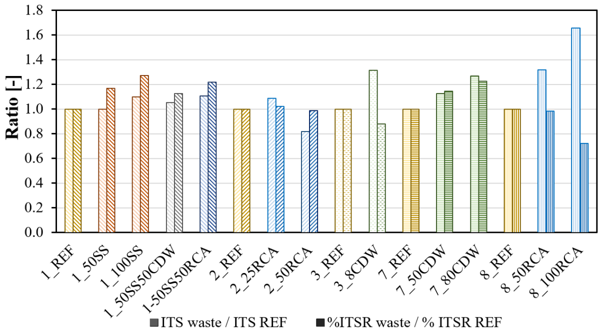

Figure 5. Indirect tensile strength ratio (ITSR) results by mixture [8].

TG4: Life cycle assessment

TG4 aimed to produce international average values of Climate Change and Energy Use resulting from asphalt mixtures associated with the production of conventional and WMR (cradle-to-gate). To achieve this current standards namely ISO 21678:2020 were used to create a methodology to define benchmarks for the environmental impact of construction products. Subsequently, a data collection tool was designed by an international group which allows gathering the necessary data to perform Life Cycle Assessment exercises from raw materials acquisition up to and including asphalt plant manufacturing (A1-A3). This tool was sent to partners to collect such information for a variety of mixtures including WMR mixtures, resulting in 16 case studies. A Life Cycle Assessment was then carried out to analyze the 14 case studies collected for asphalt mixtures focusing on two indicators: Climate Change and Energy Use. These results were used for producing benchmark values for reference (conventional) asphalt mixtures, namely, asphalt concretes (ACs) and stone matrix asphalts (SMAs). In addition, sensitivity analysis on transport distances was performed. Next, LCA exercises were performed to assess the environmental impacts of WMRs, two case studies of asphalt mixtures manufactured with selected WMRs. Climate Change and Energy Use indicators were compared to those of the benchmark values of the reference ACs as well as SMAs. As a result of these exercises: 1) environmental impacts of SMA was higher than ACs, 2) Asphalt mixtures incorporating WMRs showed to be more environmentally friendly in comparison to benchmark values of reference SMA. It is noteworthy to mention that this is not always the case when conventional ACs are used as reference.

The following conclusions can be drawn from cradle-to-gate (A1-A3) analysis:

- Raw materials supply is the most important life cycle stage when Climate Change and Energy Use are considered. A clear exception is when transport distances are particularly long. The choice of raw materials and their production or acquisition processes are therefore crucial in the assessment of asphalt mixtures' environmental impact. To this end, to reduce this impact a focus on raw materials extraction or increasing the use of recycled materials will be beneficial.
- Regarding materials, SMA mixtures seem to have higher environmental impacts than AC mixtures due to their higher content of polymer modified binder. Nonetheless, these impacts could be compensated with their greater durability, and because of that it is important to include durability when analyzing LCA of high-performance asphalt mixtures. Using more recycled materials in SMAs would also help to compensate their environmental benefits.
- In comparison to benchmark values of SMA, selected WMR mixtures were more environmentally friendly. This was not always the case the comparison was made to conventional ACs (Figure 6). In the specific case studies shown in Figure 6, the higher impact of the UGR asphalt mixture is due to the use of filler cement. If this mixture with CR is compared with a conventional asphalt mixture with the same raw materials but without CR, the CR mixture would be more environmentally friendly. This fact highlights the importance of focusing on the raw materials used for any asphalt mixture. Furthermore, they are less impactful when energy used is analyzed (figure 5). In this type of mixtures, durability will also be a critical aspect when comparing their LCA with other traditional mixtures.

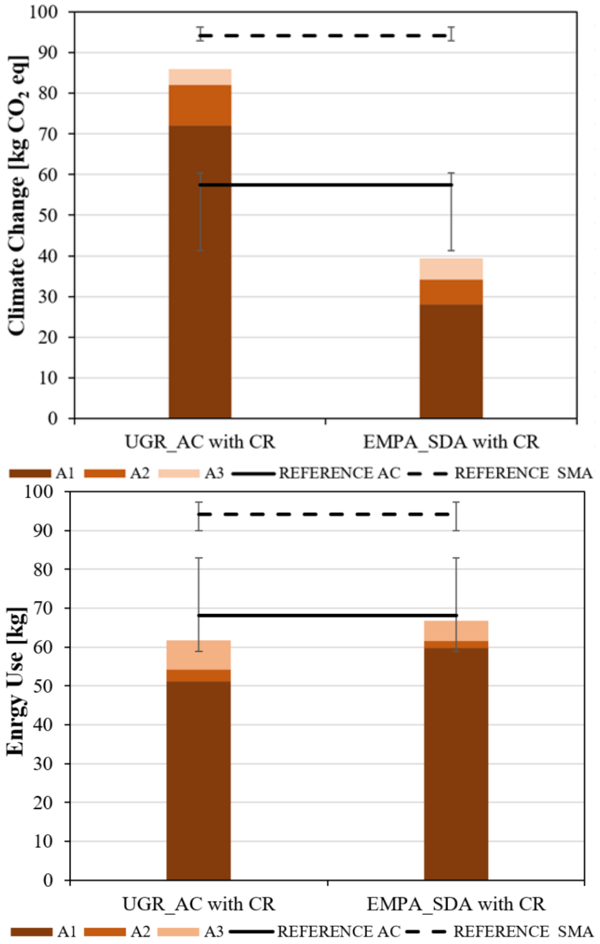

Figure 6. Climate change indicator, top, and energy use bottom, for WMR case studies compared to the benchmarks with reference target and limit [3].

Conclusions

The main findings from the work of this TC can be summarized as follows:

- Appropriate testing procedures are needed as using waste and secondary materials can result in a mixture that is susceptible to certain types of failure, such as cracking or rutting.
- Traditional test methods might not be appropriate for binders and/or mixtures with waste and secondary material. An example was the tests on the binder blends with plastic or rubber.
- Microscopy techniques and observations during testing have shown that plastic or rubber exists as elastic bodies within the mixture. These elastic bodies keep their elastic properties even when the bitumen becomes soft and viscoelastic at higher temperatures, thereby contributing to the performance.
- The degree of repeatability/reproducibility is reduced due to more inhomogeneity in resulting blends.
- Once the mix design is adjusted, such as higher binder content in some examples, similar performance in comparison to virgin materials can be achieved.
- The use of waste materials should not have detrimental environmental consequences. Therefore, environmental aspects such as leaching should be considered.
- A benchmarking exercise has shown that cradle-to-gate environmental impact of asphalt mixtures varies from mixtures to mixtures. This holds true also when waste and secondary materials are incorporated within production of asphalt mixtures. These results are limited to selected case studies, hence a tailored follow-up technical committee will aim at widening the scope to an international benchmarking on the use of alternative paving materials within asphalt mixtures.

Acknowledgements

The contribution of Empa to this work was supported by the Swiss National Science Foundation (SNF) grant No. 5211.01569 for a project titled "Urban Mining for Low Noise Urban Roads and Optimized Design of Street Canyons".

Conflict of interest

The authors hereby declare that they have no conflict of interest.

Authorship statement (CRediT)

Lily D. Poulikakos: Conceptualization, Formal analysis, Investigation, Resources, Data curation Writing - original draft, Writing – review and editing, Visualization, Supervision, Project administration, Funding acquisition. **Emiliano Pasquini:** Conceptualization, Formal analysis, Investigation, Resources, Data curation Writing - original draft, Writing – review and editing, Visualization, Supervision, Project administration. **Marjan Tusar:** Conceptualization, Formal analysis, Investigation, Resources, Data curation, Writing - original draft, Writing – review and editing, Visualization, Supervision, Project administration. **Augusto Cannone Falchetto:** Conceptualization, Formal analysis, Investigation, Resources, Data curation Writing - original draft, Writing – review and editing, Visualization, Supervision, Project administration. **Fernando Moreno Navarro:** Conceptualization, Formal analysis, Investigation, Resources, Data curation Writing - original draft, Writing – review and editing, Visualization, Supervision, Project administration. **Jorge Pais:** Conceptualization, Formal analysis, Investigation, Resources, Data curation Writing - original draft, Writing – review and editing, Visualization, Supervision, Project administration. **Davide Lo Presti:** Conceptualization, Formal analysis, Investigation, Resources, Data curation Writing - original draft, Writing – review and editing, Visualization, Supervision, Project administration. **Ana Jiménez del Barco Carrión:** Conceptualization, Formal analysis, Investigation, Resources, Data curation Writing - original draft, Writing – review and editing, Visualization, Supervision, Project administration. **Di Wang:** Formal analysis, Investigation, Resources, Data curation

Writing - original draft, Writing – review and editing, Visualization.

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